

17. *The OVERTHRUST TORRIDONIAN ROCKS of the ISLE of RUM, and the ASSOCIATED GNEISSES.* By ALFRED HARKER, Esq., M.A., F.R.S., F.G.S., Fellow of St. John's College, Cambridge; Geological Survey of Scotland.<sup>1</sup> (Read March 11th, 1903.)

## [PLATE XIV—MAP.]

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## I. INTRODUCTION: THE RELATIVELY-UNMOVED TRACT.

THE geological literature of the Isle of Rum is not extensive. The earliest important contribution is found in Macculloch's 'Western Islands of Scotland,' and illustrates the close observation and acute reasoning which characterize that remarkable work.<sup>2</sup> In his small sketch-map Macculloch shows the northern part of the island and a strip along the eastern coast occupied by red sandstone, which he correctly identifies with that of Skye [Torridonian]. The rest of the island he divides among the igneous rocks, of which he distinguishes syenite [granite and granophyre], 'augit-rock' [peridotite, gabbro, etc.], and basalt and amygdaloid. In spite of the extremely crude topography of the map, the distribution of these rocks is roughly indicated, and some of the leading facts concerning their relations are set forth in the text. Since Macculloch's time no systematic account of the geology of Rum has been published. The igneous rocks, now recognized as of Tertiary age, have received some notice, and a valuable description of the peridotites in particular has been given by Prof. Judd.<sup>3</sup> Numerous references to Rum appear in the writings of Sir Archibald Geikie; and in 'The Ancient Volcanoes of Great Britain' he has given an account not only of the igneous rocks, but also of some of the highly disturbed strata, with associated gneisses, to be described below.<sup>4</sup> The present communication is the outcome of the detailed mapping of the island carried out by the writer for the Geological Survey of Scotland.

<sup>1</sup> Communicated by permission of the Director of H.M. Geological Survey.

<sup>2</sup> John Macculloch, 'A Description of the Western Islands of Scotland' ... vol. i (1819) pp. 473-506; also map facing p. 71 of Atlas, and section on pl. xix, fig. 5. The direction of the section in that figure is incorrectly stated; the letters S. and N. should be N.W. and S.E.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xli (1885) pp. 354-416.

<sup>4</sup> 'Ancient Volcanoes of Great Britain' vol. ii (1897) pp. 349-55.

The Isle of Rum divides, on the broadest view, into a northerly moorland-tract, the highest points of which fall a little short of 1000 feet, and a southerly mountain-tract, of much bolder relief, and reaching a maximum altitude of 2659 feet. The mountains are formed of massive plutonic rocks of Tertiary age, and, as Macculloch remarked, these, at least in the eastern part of the island, overlie the stratified rocks. Torridonian strata occupy about one-half of the total area, including the northern moorland-tract and a strip along the eastern coast, as shown in the accompanying sketch-map (Pl. XIV). The highly-disturbed strata to be particularly described occur in two districts, namely, a small area in the north-western part of the island, and a more extensive belt along the north-eastern and eastern border of the mountains.

I shall give, first, a short general account of the relatively undisturbed strata which occupy the greater part of the Torridonian area. They consist principally of a monotonous succession of sandstones, dipping north-westward or west-north-westward, at angles usually between  $20^{\circ}$  and  $33^{\circ}$ ; but below these emerges, on the eastern coast, a group of shales with similar dip.<sup>1</sup> The total thickness, as calculated from the extent of the rocks and the observed dips, is more than 10,000 feet, without any natural base or summit, and this thickness is distributed approximately as below:—

Upper group : sandstones, 9000 feet seen.  
Lower group : shales, 1400 feet seen.

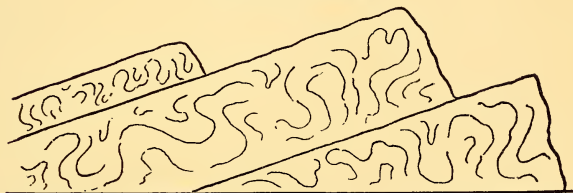
The upper group consists almost exclusively of felspathic sandstones, which have a more or less pronounced reddish colour, except where they have been bleached by metamorphism or some other agency. The texture varies from fine to coarse, many beds containing abundant small pebbles up to an inch or more in diameter. The lower group consists essentially of dark shales, of very uniform aspect where they have not been metamorphosed in the vicinity of igneous intrusions. There are, however, occasional beds of fine grey sandstone at various horizons; and some alternations of similar sandstones with shales at the summit of the group may be regarded as passage-beds to the sandstones above.

In this—which we have styled, with implied reservation, the relatively-undisturbed tract—there is, apart from some faults of moderate throw, the appearance of an unbroken succession with a gentle and steady inclination. This apparent regularity is, however, as Sir Archibald Geikie has remarked, in great measure illusory, and the estimates of thickness given above must be qualified accordingly. The stratification is in reality highly disturbed on a small scale. The sandstones, which present so monotonous a succession of steadily-inclined beds, show on closer examination in innumerable places indications of violent contortion, these indications being brought out by weathering in almost all parts of the coast-section,

<sup>1</sup> Macculloch ('Western Is.' vol. i, 1819, p. 481) observed these shales, but identified them erroneously with the [Liassic] shales of Loch Eishort in Skye.

and at many places on the exposed tops of the moorland-hills (fig. 1). In the shales contortion on a small scale is probably not less widespread; but it assumes a somewhat different form, which is apt to elude cursory observation. The bedding is often seen to be affected by extremely sharp zigzags, which are in fact small and very acute isoclinal folds thrust over until their axial planes are nearly parallel with the general direction of stratification.

Fig. 1.—*Torridonian sandstones on the shore at Camas Pliasgaig, Rum.*



[The appearance of regular dips is shown in strata which are nevertheless highly contorted on a small scale.]

The Torridonian strata are intersected by numerous intrusions of peridotite and gabbro, omitted in the sketch-map (Pl. XIV) in order to avoid complication, and metamorphic effects are to be observed in the immediate neighbourhood of these. The most universal and conspicuous change consists in a decoloration of the red sandstones, and the border of bleached rock surrounding the intrusive mass is often visible at a distance. In contact with the more considerable intrusive rock-masses, the sandstones have experienced metamorphism of a higher grade, involving partial reconstitution. Some consist of recrystallized quartz and felspar, the latter in subordinate amount, with some new-formed accessory mineral, usually brown mica. Not infrequently the metamorphosed rock exhibits a certain quasi-spherulitic structure, which is conspicuous on a weathered surface. A good example is afforded by the altered sandstones bordering a picrite-intrusion at Airidh Thalabhairt, on the north side of Kinloch Glen. Thin slices show that the felspar recrystallizes more readily than the quartz, and often assumes a radiate arrangement which gives the peculiar appearance just noticed. In this recrystallized feldspathic aggregate the quartz-grains are often seen apparently unchanged.

Besides the small plutonic intrusions, there are, in the relatively-undisturbed Torridonian tract, very numerous dykes and sheets of basalt. These have not, in general, given rise to any sensible metamorphic effects. There are, however, certain remarkable occurrences which call for special notice, since they have a bearing on the connection between crushing and brecciation, on the one hand, and igneous injection and metamorphism, on the other.

In the tract under consideration the mechanical effects of crushing are nowhere exhibited on the scale shown in the submontane

belt, to be described below ; but local brecciation is not an uncommon incident, and it usually shows a certain orderly disposition. In addition to gently inclined crush-bands, which are comparable with surfaces of overthrusting, there are others with vertical position, which are rather the analogues of normal faults. These may be connected with the great Palæozoic crust-movements of the region, or they may be of Tertiary date : in the absence of all formations between Torridonian and Tertiary, the question cannot be brought to a decisive test. These vertical crush-bands are not widely distributed, and are best studied in the Kilmory district. A good example crosses the river about a mile above the deserted hamlet : this is about 15 feet wide. Others on the neighbouring hills attain locally a greater breadth, but they usually die out in a short distance when followed along their length. They are conspicuous owing to the bleaching of the red sandstone, an effect which has been already remarked as a constant incident of thermal metamorphism, though it is not strictly confined to those circumstances. Such a brecciated and bleached band usually shows, at least in some part of its length or its width, an injection with igneous material. The invading magma has probably been an ordinary basalt, but it has been considerably modified by absorbing silica, with a certain amount of alkalis, etc., from the sandstone. Thin slices [10486, 10504<sup>1</sup>] show a very intimate admixture of the two rocks, abundant sand-grains in a partly-corroded state being embedded in a matrix of igneous origin. The bulk of the latter consists of slender felspar-crystals with a strong tendency to radiate arrangement, as in many of the so-called 'variolites.' The extinction-angles are quite low, indicating somewhat acid varieties, and it is probable that alkali-felspars are present. The ferromagnesian element is represented by numerous little pale-green or yellow serpentinous pseudomorphs, apparently replacing a rhombic pyroxene. Granules of epidote are also found ; but it is not clear whether these are of metamorphic origin or due to subsequent alterations.

The amount of igneous material in these injected crush-bands varies greatly, affording every gradation from a basalt-dyke crowded with fragments of sandstone to a brecciated grey sandstone free from basalt ; and such variation may be observed within a short distance along the length of a given band, or even across its breadth. The sandstone, when not impregnated in the manner described, is notably metamorphosed, often showing the quasi-spherulitic structure already noticed in another connection (p. 191). The metamorphism generally seems excessive, in comparison with the amount of igneous material, and there is frequently very marked metamorphism in places where no basaltic or other intrusion is to be detected. Thus, on the slope west and south-west of Loch an Tairbh, about  $1\frac{1}{4}$  miles north-east of Kilmory, a pale band is traceable through the red pebbly sandstones for nearly 500 yards in a south-south-westerly

<sup>1</sup> These numerals in brackets are the index-numbers of the rock-slices in the Geological Survey Collection.

direction. In parts of its course it is merely a band of bleached and metamorphosed sandstone with more or less evident brecciation; but in other places part or the whole of its width has been injected with the basalt-magma, and reactions have ensued between the two rocks. Sometimes the igneous rock forms a matrix exceeding in amount the sandstone-fragments which it encloses. This band or dyke ranges up to 6 feet in width, and in one place it bifurcates. A shorter band a little farther north reaches locally a width of 50 feet, but only a small portion of this width, on the western border, is injected with basalt, although the sandstone is conspicuously metamorphosed throughout. Here, as in other cases, the effects are narrowly localized, the sandstone immediately bordering the crush-band showing no perceptible alteration.

Whatever be the date of the crushing, it is reasonable to assume that the igneous injection is of Tertiary age, as are the numerous basalt-dykes in the same district. The reactions noticed are precisely like those observed by the writer in many Tertiary dykes in Skye, where a basaltic magma has enclosed quartz of extraneous origin. The special interest of the occurrences here described lies in the very clear evidence of metamorphism, unmistakably of thermal type, in many parts of these crush-bands where no igneous rock is visible. To suppose that the present surface of the ground happens to coincide almost exactly with the upward limit of the basaltic injections would be a highly artificial hypothesis; for the instances are numerous, and occur at altitudes varying from 100 to 800 feet within a distance of three-quarters of a mile. The phenomena described rather suggest that, under certain conditions, notable metamorphism may be effected by some kind of solfataric agency, operating along vertical bands of rock disintegrated by crushing.

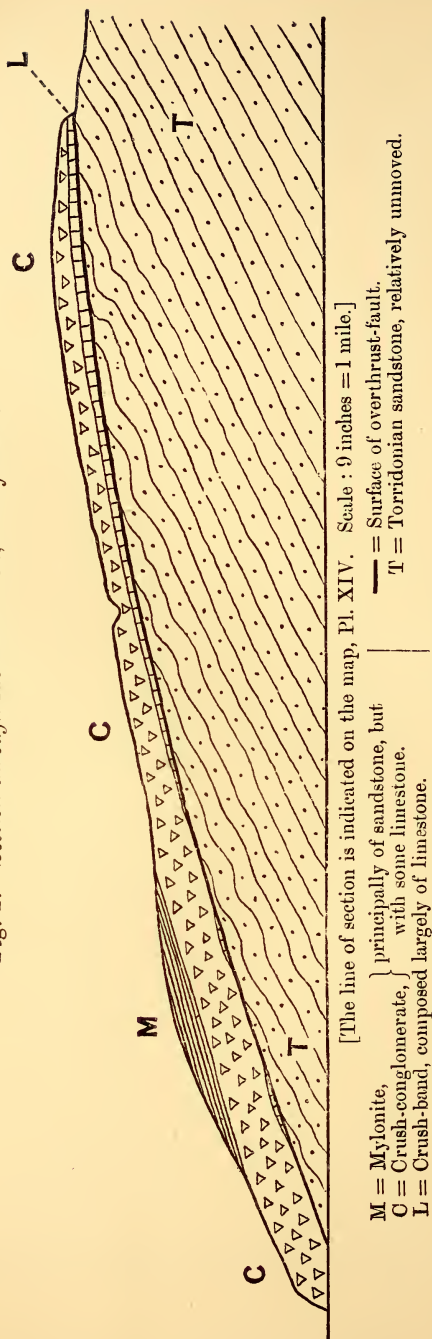
## II. THE MONADH-DUBH OVERTHRUST.

Passing now to the more highly disturbed districts, we turn, first, to the small area in the north-western part of the island, where the hilly moorland named Monadh Dubh rises to an altitude of about 800 feet. A part of this is made by a cake of overthrust rocks, measuring about 1 mile by two-thirds of a mile, resting on the ordinary red sandstones of the district and cut off to the north-west by the sea. The present limits and general disposition of the overthrust mass are well displayed, the boundary being marked by an escarpment, which runs round from coast to coast, but is most prominent on the southern and south-eastern sides. The eastern boundary is highly irregular in ground-plan, depending on the details of the surface-relief, while the general inclination of the overthrust-surface does not here differ greatly from the slope of the hill. The base of the overthrust cake of rocks, marking the main surface of movement, inclines to the north-west, the dip being gentle in the higher part, but increasing seaward to about  $20^\circ$  (see section, fig. 2, p. 194).

N.W.

S.E.

Fig. 2.—Section through Monadh Dubh, Isle of Rum.



[The line of section is indicated on the map, Pl. XIV. Scale : 9 inches = 1 mile.]

M = Mylonite,  
 C = Crush-conglomerate, } principally of sandstone, but  
 L = Crush-band, composed largely of limestone.

— = Surface of overthrust-fault.  
 T = Torridonian sandstone, relatively unmoved.

The strata immediately below show to the eye no sign of extraordinary disturbance. They are red sandstones, of fine to medium grain, with a north-westerly dip of  $15^{\circ}$  to  $25^{\circ}$ , agreeing with the normal inclination throughout the northern part of Rum.

Immediately above the surface of overthrust comes a remarkable band composed largely of crushed limestone. This is mingled with sandstone, usually in a bleached condition, and the two rocks are brecciated and in part ground down together; but there are numerous unbroken lenticles of limestone, some many feet long. They contain abundant cherts, and undoubtedly belong to the Cambrian (Durness) Limestone Series, which has not been found in place on this island. The nearest known outcrops are in the Ord district of Skye, about 17 miles away to the east-north-east; but the limestone-material of Monadh Dubh has presumably come from a south-easterly direction. The calcareous band does not usually

exceed a few feet in thickness, and it is not continuous everywhere. It is best seen on the eastern side of the area. Along the southern border it is in most places wanting, though lenticles of limestone are found at intervals at the base of the overthrust rocks.

To this basement-band succeeds a much greater thickness of crush-breccia, which we may estimate at 100 to 150 feet. The material is red sandstone, only occasionally bleached. Limestone-fragments occur, but in very small proportion, though there are some larger lenticles of that rock, especially towards the base. The accumulation is more properly a crush-conglomerate than a breccia, for most of the sandstone-fragments are more or less rounded, and many of them have the shape of rolled pebbles. There is a certain amount of finer material forming a matrix, and doubtless derived from the grinding down of the angles of the fragments.

It may be remarked, in passing, that the breccia or conglomerate is in two places traversed by vertical crush-bands, partly impregnated with basalt in the fashion described in the preceding section (p. 192). This lends support to the supposition that these vertical crush-bands are quite distinct from the main system of disturbances, and are probably of Tertiary date. The bands have the same general direction as the neighbouring basalt-dykes.

Above the crush-conglomerate, and rather sharply marked off from it, is a rock which gives evidence of crushing of a more advanced kind, and may be termed a mylonite. As a consequence of the present eroded form of the land-surface, it is preserved only in the north-western half of the area, and the crush-conglomerate emerges again from beneath it along the coast-line. The thickness thus remaining is about 70 or 80 feet. The rock is of a dull brownish colour, and has a highly-schistose structure, breaking in the manner of a shale. It consists essentially of sandstone ground down and rolled out as if it had passed through a mill, as aptly expressed by Prof. Lapworth's term 'mylonite.' The fissile character is connected with the presence of new-formed mica. There is not much calcareous matter in the body of the mylonite, but small lumps of limestone are sometimes enclosed, usually indicated by cavities from which the carbonate has been removed in solution. There are also a few large lenticles of the kind noticed lower down in the section. It is remarkable that the limestone has resisted crushing down much more effectually than the sandstone.

As a minor point of interest it may be noted that, both here and in the brecciated rocks below, the fragments of Durness Limestone have not suffered the dolomitization which has affected so large a portion of that group in districts where it occurs in place. The pebbles of the same limestone in the Triassic conglomerates of Skye, Raasay, and Scalpay are also non-dolomitic.

The occurrence of this area of highly-disturbed rocks as an isolated outlier seems to preclude any direct examination of its tectonic relations, as connected with the system of crust-movements

which has produced the existing arrangement. The infraposition of the crushed limestone, and the fact that the evidences of profound mechanical disturbance become more pronounced as we pass upward in the section, suggest that the whole overthrust mass is in an inverted position beneath a more important plane of overthrusting, the position of which is not far above the present surface of the ground. Such a hypothetical major overthrust might perhaps be identified with that which traverses the centre of the island, to be described below. The belt of country neighbouring the overthrust area of Monadh Dubh shows, however, some phenomena which are not without a bearing on the subject, although the evidence obtained is only of a fragmentary nature. The red sandstones immediately beneath the crushed and displaced rocks give, as has been stated, no clear indication of any special disturbance. A little farther away, however, towards Loch Sgaorishal, occurs a narrow band, along which the rocks are highly inclined and greatly crushed. It follows a rather irregular and curved course in a general south-westerly to north-easterly direction, at a distance of 100 to 300 yards from the outcrop of the Monadh-Dubh overthrust, and can be traced for about 900 yards, dying out, so far as any palpable evidence is concerned, in both directions. It is much obscured by a boss of pierite and other smaller intrusions. Along this band the sandstone is not only brecciated, but in certain places mylonitized. Further, a certain proportion of crushed limestone is in some parts mingled with the sandstone, and there are lenticles of less crushed limestone, with cherts, like those noticed above. The appearances seem to show that the north-western boundary of this crush-band is a surface of discontinuity comparable with the Monadh-Dubh 'thrust-plane,' but inclined at a high angle. Although much more narrowly localized than in the other case, the differential movement has been of an extreme kind; and the highly-sheared sandstone, with its abundant development of white mica in parallel flakes, is a typical mylonite [10498].

### III. THE OVERTHRUST BELT OF THE MOUNTAIN-BORDER.

We now proceed to consider the more extensive area of overthrust and highly-disturbed Torridonian strata in the east-central, eastern, and south-eastern part of the island, where, as shown in the sketch-map (Pl. XIV), it forms a belt along the north-eastern and eastern border of the mountain-tract. The Tertiary plutonic rocks, of which the mountains are built, consist in this district of a succession of roughly-parallel and partly-interlacing sheets or laccolitic bodies with a general inward dip. Viewed broadly, they have been intruded not far from, and usually above, the main surface of overthrusting. In places they transgress this surface, cutting into the relatively-unmoved strata below. In the western part of Rum the quasi-stratiform disposition of the plutonic masses

is to a great extent lost, and the intrusions, extending farther northward, entirely cut out the overthrust belt.

The curved course of the outcrop of the overthrust surface, following the outward slope of the high ground, permits us to regard that surface as having on the whole a gentle inclination towards the south-east. Regarding this course in detail, however, and in relation to the minor features of the ground, we see that the surface must be in reality greatly warped, and has in some places a rather high inclination to the horizontal. Along a great part of its length the outcrop of the overthrust runs at altitudes between 1000 and 400 feet, but in the south-east of the island it rises considerably higher inland, and at the same time comes down to sea-level at the coast. This is seen on Beinn nan Stac, where the average inclination of the overthrust surface does not differ much from the seaward slope of the hill (see section, fig. 4, p. 202).

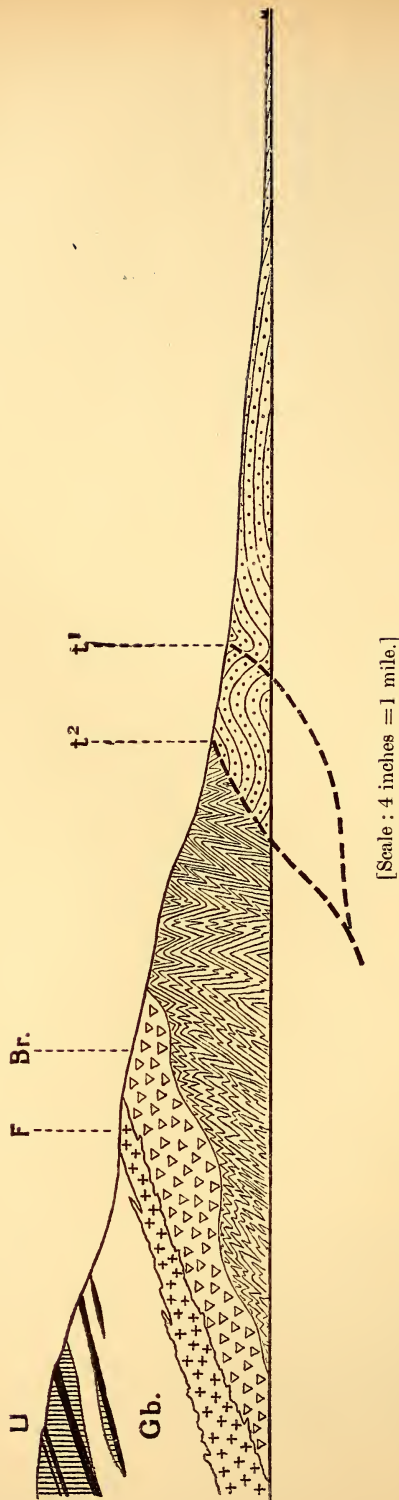
The outcrop of the overthrust surface is easily mapped, for the effect of the displacement is, in general, to cause the shales of the lower group to rest on the sandstones of the upper. The overlying displaced rocks have suffered very great mechanical disturbance, as is shown by their high and variable dips and violent contortion, and in some places by brecciation on an extensive scale. The relatively-unmoved strata below are much less disturbed, sometimes not more so than in the north of the island; but along parts of the line they have an altered and steeper dip, and in certain places they are brecciated. The voluminous intrusions of peridotite, gabbro, granite, etc., have given rise to considerable metamorphism of the thermal type, superposed upon the dynamic effects. The results of such metamorphism are more often conspicuous in the displaced strata than in those below the overthrust; but this is only a necessary consequence of the overlying position of the igneous rock-masses. There is no essential connection between the dynamic and the thermal transformations, and the latter seem to stand always in direct relation to the proximity of the large plutonic intrusions. The phenomena of metamorphism of the crush-breccias and numerous other circumstances enable us to affirm that the thermal metamorphism was subsequent to the dynamic, and its distribution warrants us in ascribing it, in the main if not wholly, to the Tertiary intrusions. In making this statement we ought to reserve the case of certain gneissic rocks, found above, and sometimes below, the overthrust surface, which will be discussed farther on.

The belt of displaced rocks will now be considered in more detail, beginning at the centre of the island. To the west the overthrust strata are cut out (as has been remarked) by the igneous intrusions, which in this part assume something of the boss-like habit. The overthrust is first met with a little to the east of the north-and-south valley in which lies Loch Sgathaig or the Long Loch. The main line of the displacement follows here a very sinuous course, though with a general easterly direction, and it is interrupted in

S. 30° W.

N. 30° E.

Fig. 3.—Section from Barkeval Pass (east of Barkeval) to Kinloch Castle, Isle of Rum.



Towards Kinloch the relatively-unmoved Torridonian sandstones are seen in their natural position. The heavy broken lines ( $t^1$  and  $t^2$ ) represent minor and major overthrusts respectively. Above come highly contorted Torridonian shales, succeeded by a crush-breccia of sandstone and shale (Br.). To the left appear the lowest members of the stratiform complex of Tertiary intrusive rocks, namely:—

U = Ultrabasic group, with alternations of more and less felspathic types.		Gb = Gabbro.
		F = Porphyritic quartz-felsite.

several places by abruptly-intruded igneous masses. The relations are of a complicated kind, and it appears that more than one overthrust occurs. The displaced strata are mostly shales in a metamorphosed state, and they have high dips, often approaching the vertical, in various directions, but chiefly to north and north-east. The metamorphism is not always of a very advanced grade, the only conspicuous new mineral being brown mica in flakes set parallel to the lamination. The angular granules of quartz, which are abundant in some beds, are quite unaltered [10489, 10490]. Some associated sandstones, evidently metamorphosed, also show the formation of brown mica, the detrital grains of quartz and felspar being unchanged [10488]. In another specimen the alteration is greater, the elastic structure being partly obscured. Here some green hornblende has been produced, and in places granules of a pale augite, apparently along a veinlet which has contained a little calcareous matter [10487]. A crush-breccia, which occurs in a few patches of no great size, has also undergone metamorphism.

The line of the overthrust runs eastward, passing north of Loch Bealach Mhic Neill and Loch Gainmich, and then turns more to the south-east. All along this line the sandstones below, or to the north of, the main overthrust show no special sign of disturbance, except a change of dip. As we approach from the north, the inclination of the strata becomes steeper, and takes a northerly direction, and as we pass eastward the dip becomes east of north, that is, still away from the overthrust. In Coire Dubh, opening north-eastward towards Kinloch, these highly tilted sandstones are cut off by a subsidiary surface of movement, and below this minor overthrust the beds have the normal inclination (see fig. 3, p. 198).

In that portion of the displaced belt of rocks which we have followed so far, sandstones are seen in several places above the main surface of the movement. They occur always south of the overthrust shales, which they doubtless succeed, though the observed dips show that the actual junction is not a natural one. The small areas of crush-breccia, which have been mentioned, are found in like situations, and it appears that the conjunction of sandstones and shales has favoured the production of the brecciated structure. It has already been remarked that the undisturbed succession shows a certain alternation of shales and sandstones at the boundary between the two groups, and it is to be supposed that the unequal yielding of the two rocks under mechanical forces would conduce to the setting up of brecciation. The conditions were indeed comparable, in many respects, with those which affected the Manx Slates as described by Mr. Lamplugh.<sup>1</sup>

The most considerable mass of crush-breccia in Rum is that which crosses Coire Dubh (fig. 3), and forms much of the slopes of Meall Breac and Cnapan Breaca on the two sides of the corrie. Though

<sup>1</sup> Quart. Journ. Geol. Soc. vol. li (1895) pp. 563-88; & 'The Geology of the Isle of Man' Mem. Geol. Surv. (1903) pp. 55-58.

cut off to the west and south by intrusive rocks, it has a length of a mile and a width varying up to a quarter of a mile. Its actual thickness is not easily estimated, but is probably about 400 or 500 feet. This occurrence was noticed by Sir Archibald Geikie.<sup>1</sup>

A description of this crush-breccia will apply also to the smaller patches mentioned above. It is a rock of striking and characteristic aspect. In most places both sandstone and shale enter into its composition, fragments of grey sandstone being embedded in a darker and nearly black matrix which consists largely of crushed shale. There are, however, fragments of shale also, though they are less abundant, while, on the other hand, the sandstone has contributed in varying amount to the comminuted matrix. The fragments usually range in diameter from 2 or 3 inches downward, though blocks of larger dimensions are also found. The angles are in general more or less rounded, but the sandstone-fragments have not undergone so advanced a degree of attrition here as at Monadh Dubh: a fact attributable perhaps to the interposition of the softer shale. It is noticeable that the sandstone in the breccia is mainly of the fine-grained grey variety found in the passage-beds to which I have alluded, confirming the supposition that the breccia is formed in great part by the breaking up of those beds. Immediately overlain by the massive plutonic rocks of the mountain-tract, and invaded, moreover, by two considerable masses of a peculiar porphyritic felsite, the breccia is in most parts more or less metamorphosed; the sandstone in it being sometimes almost converted into a quartzite, while the shale is much indurated and otherwise altered. It is clear that this metamorphism is posterior to the brecciation, even apart from any evidence as to the Tertiary age of the intrusions. The porphyritic felsite is in some places crowded with fragments picked up from the breccia, and it also encloses a large amount of gabbro-débris in a partly-digested state.

The limestone which was so noteworthy a feature of the Monadh-Dubh breccia is wanting here, nor have I detected fragments of that rock in any of the breccias in this belt of country; but Sir Archibald Geikie noted a patch of limestone in Glen Dibidil.

Following the main surface of overthrust south-eastward from Coire Dubh, we find that a little before reaching Allt Mòr na h-Uamha it is cut out by the encroachment of the gabbro, and is lost for about 900 yards. It reappears at the point where the Dibidil footpath crosses the next burn, Allt na h-Uamha, and is there thrown down a little by a normal fault. Its course is now nearly north and south. The shales above are, as usual, highly inclined and contorted, and they are also indurated owing to the proximity of the gabbro. The sandstones below have only a small thickness, being underlain by the shale-group in its natural position, and the dips are quite normal. Indeed, from here to near Dibidil, a distance of  $2\frac{1}{2}$  miles, the strata below the overthrust show, in general, no

<sup>1</sup> 'Ancient Volcanoes of Great Britain' vol. ii (1897) pp. 351, 352.

special signs of disturbance, excepting the contortions on a small scale which seem to affect most of the Torridonian rocks of Rum. The overthrust shales are soon cut out again by the gabbro, and only reappear for a short distance about three-quarters of a mile farther south.

We pass on to Beinn nan Stac, a hill about 1850 feet high, the south-eastern slope of which descends rather sharply to the sea (see fig. 4, p. 202). The average inclination of the overthrust-surface in this place does not differ greatly from that of the ground, so that the displaced shales make a considerable spread on the slope. They may be regarded as of the nature of an outlier, this relation being obscured, however, by the subsequently-intruded gabbro and felsite to the north-west. The shales are highly inclined, often vertical, and their strike varies rapidly from point to point. They are also violently contorted on a small scale, and indurated in consequence of metamorphism. Fine grey sandstone, for the most part thoroughly brecciated, forms the actual summit of the hill, this mode of crushing having been especially operative, as usual, at the passage from shale to sandstone. Nearly along this zone of weakness has been intruded a sheet-like mass of porphyritic felsite similar to that of Meall Breac, and here, too, it has in many places enclosed fragments of sandstone from the crush-breccia. The shales themselves are brecciated in some places, but not on an extensive scale. The relatively-unmoved sandstones below the overthrust are more disturbed on Beinn nan Stac than elsewhere along the line that we have followed, and immediately below the main surface of displacement they show high and reversed dips.

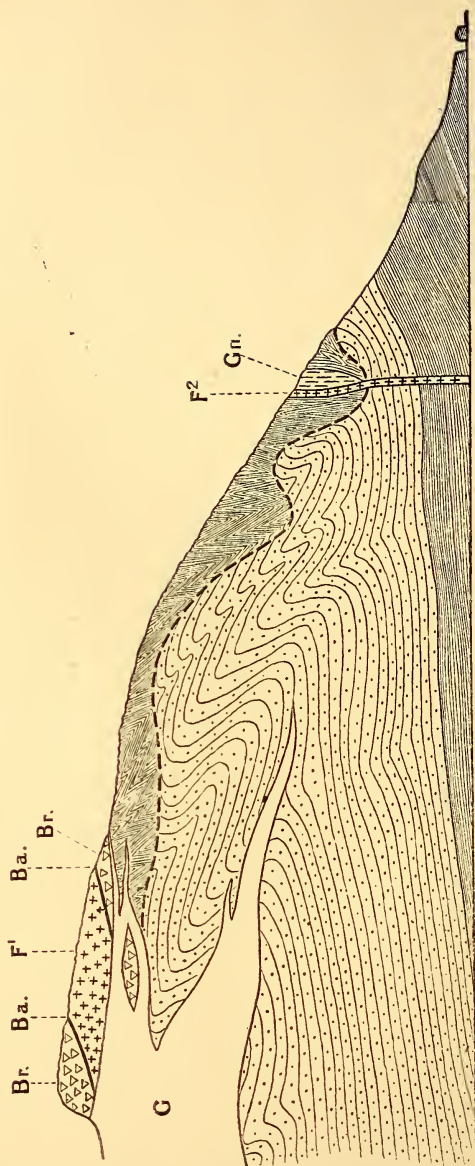
The overthrust outlier of Beinn nan Stac, with much reduced width, comes down to the sea a little east of the outlet of the Dibidil River. Beyond this the strata beneath the overthrust show much more evident disturbance than heretofore, the sandstones being extensively brecciated. There is in places considerable metamorphism, which is here connected with the occurrence of several patches and lenticles of gneiss. Highly-disturbed Torridonian rocks extend up to a rather high altitude on the east side of Sgùrr nan Gillea, and run along the coast for some distance towards Papadil; but our detailed survey has not yet covered the actual termination of the belt of displacement in this direction.

#### IV. THE GEOLOGICAL RELATIONS OF THE GNEISSES.

I have next to notice what is, in some respects, the most interesting feature of the tract under consideration, namely, the occurrence of gneissic rocks at numerous places along the border of the mountains, usually in immediate association with the highly-disturbed Torridonian strata.

The individual occurrences are never of large dimensions, the length being usually less than a quarter of a mile, and sometimes as little as 100 yards. Where the natural boundary is clearly shown, it approximates more or less closely to a lenticular form,

Fig. 4.—Section through *Beinn nan Stac* to the coast of *Stac nam Faoileann*, *Isle of Rum*.  
N. 55°W. S. 55°E.



[The line of section is indicated on the map, Pl. XIV. Scale : 6 inches = 1 mile.]

The heavy broken line represents the warped surface of overthrusting. Below this the Torridonian shales and sandstones occur in their natural position. Above, the shales are violently contorted and the sandstones brecciated (Br). A lenticle of gneiss (Gn) is shown among the contorted and metamorphosed shales in the lower part of the slope. The other rocks represent normal igneous intrusions of the Tertiary suite, namely : —

G = Gabbro. F' & F<sup>2</sup> = Porphyritic quartz-felsite. Ba = Basalt-sheets intruded along the border of the felsite.

The laccolithic mass of felsite (F<sup>1</sup>) is not cut off by the gabbro, but is of later date, intruded along the zone of brecciation and stopped by the more massive gabbro.

with its greatest extension conforming with the local strike of the disturbed strata in its vicinity. A number of detached and partly-detached areas of gneiss occur in the central part of Rum, near the western termination of the overthrust belt, the bare white outcrops about Priomh-loch being very conspicuous at a distance. This is a good district for studying the petrography of the rocks, but not their relation to the Torridonian, the map being complicated by irregular intrusions of peridotite, gabbro, and granite. Following the disturbed belt from Loch Bealach Mhic Neill eastward and southward, no gneiss is seen for a long distance, except a small strip, in contact with Torridon Sandstone, involved in the porphyritic felsite on the hill east of Loch Gainmich. Next, a lenticular mass of gneiss occurs among the altered shales just above the overthrust surface on the lower slope of Beinn nan Stac (fig. 4, p. 202). A strip runs for nearly 400 yards along the Dibidil River, from the ford to the coast, and there are several other occurrences to the west and south-west. It is only in this district, where the strata overridden by the great displacement are unusually disturbed, that gneissic rocks are found below the main overthrust. In addition to these occurrences, all more or less closely bound up with the displaced Torridonian strata, gneisses are found about Loch Sgathaig bounded only by granite, gabbro, and picrite; while, farther west, an isolated patch a quarter of a mile long occurs in the interior of the main granite-area, forming the summit of Beinn a' Bhàrr-shaibh, to the east of Orval.

These rocks, with well-marked parallel banding and foliation, and frequent alternations of different lithological types, are perfectly characteristic gneisses in the ordinary descriptive sense of the word. Indeed, their appearance led Sir Archibald Geikie to assign them to an Archæan age.<sup>1</sup> Closer examination, however, compels me to dismiss decisively the hypothesis that these rocks are portions of a pre-Torridonian formation brought up by overthrusting. The gneisses are clearly intrusive in the Torridonian strata. Not only do they penetrate these in an intimate manner, but they sometimes enclose fragments of them in a highly metamorphosed state. Thermal metamorphism, as I have remarked, has affected in varying degree a large portion of the disturbed strata along the mountain-border, and I have ascribed it in general to the intrusion of the gabbro and other plutonic rocks of Tertiary age; but the highest grade of metamorphism is found in the rocks bordering the relatively-small intrusions of gneiss. On the lower slope of Beinn nan Stac, for example, for a considerable distance from the lenticle of gneiss, the contorted shales are converted into a hard black, almost flinty rock, resembling a compact basalt. Elsewhere sandstone has been transformed into quartzite.

We have, then, full assurance that the gneisses are younger than

<sup>1</sup> 'That some of these rocks are portions of the Lewisian Series can hardly be doubted, and their structure and relations are probably repetitions of those between the Lewisian gneiss and Torridon Sandstone of Sleat in Skye,' *Ancient Volcanoes of Great Britain*, vol. ii (1897) p. 351.

the Torridonian strata with which they are in most cases associated. It remains to enquire their relation to the next marked epoch in the geological history of Rum, namely, that of the overthrusting, which we may safely correlate with the great Palæozoic crust-movements in other parts of the Scottish Highlands. In no case is there anything to indicate that the gneisses themselves have been moved. The boundaries of the lenticular masses, which on that supposition would be favourable places for shearing and faulting movements, seem to be in fact, so far as they are exposed, normal igneous junctions. The lenticular form and the general parallelism with the local strike are features common in ordinary laccolitic intrusions, and due to the natural tendency of an intruded magma to follow the direction of least resistance. Moreover, this parallelism does not extend to the gneissic banding, which is certainly of the nature of a primary flow-structure. With rare exceptions, the gneisses show no sign of crushing, brecciation, or internal fracture of any kind. Some of the occurrences are in the immediate neighbourhood of, or even in contact with, crush-breccias; but the gneisses have not contributed to the composition of these breccias, a fact inexplicable if the crushing be supposed posterior to the intrusion of the gneiss. The Dibidil district does, indeed, afford a certain exception to this generalization, for there brecciated gneiss is seen in one or two places. Such occasional phenomena do not, however, invalidate the argument; for, apart from all consideration of these gneissic rocks, it is probable that, here as elsewhere, there was in Tertiary times a renewal of mechanical disturbance along the old lines, though with much less intensity. Brecciation and other effects of crushing are found on a much more extensive scale than at Dibidil in undoubted Tertiary granites and gabbros in some parts of Skye. The observations which have been adduced warrant us then in believing that the gneissic rocks of Rum were intruded at some time posterior to the great crust-movement of the region. This conclusion still leaves two alternatives open: the intrusion of the gneisses may conceivably have followed the overthrusting after no long interval, being a later incident of the same great system of disturbances, or it may be referable to a distinct and long posterior epoch. The only later igneous intrusions known to have affected this part of Scotland are those of the Tertiary suite, and the question of the date of the Rum gneisses turns, therefore, upon the relations of these rocks to those of admitted Tertiary age, which are abundantly represented in the same tract. We shall see that the observed relations afford somewhat strong ground for believing that the gneisses are of late geological date, and are merely special phases of the plutonic intrusions of the mountains.

The rocks building the large intrusive bodies fall into three principal groups, which succeeded one another in order of decreasing basicity: (i) the ultrabasic group, comprising peridotites, olivine-anorthite-rocks, enstatite-anorthite-rocks, and many other varieties; (ii) gabbros; (iii) granites, including granophyres. In

addition to these plutonic rocks, there is the peculiar porphyritic quartz-felsite already mentioned, of somewhat later date, confined to the overthrust belt and generally intruded among or in contact with the crush-breccias. Since the prevalent rock among the gneisses is always of acid composition, it is with the third group, if any, that we must correlate it. The rocks which we have mapped as gneiss and granite, respectively, come together in the central part of the island, about Loch Sgathaig. The ground here is much obscured by peat, and the boundaries laid down are merely empirical, being drawn to divide as simply as possible the outcrops which show gneissic banding from those which do not. There is nothing inconsistent with the supposition that the two are parts of one and the same mass, but the exposures are not sufficient to warrant a conclusion either in that sense or the opposite. Farther west, on Beinn a' Bhàrr-shaibh, the evidence is much clearer. Here a patch of well-characterized gneiss, mainly of granitic composition, but with some basic material, forms the summit of the hill, and extends for some distance down the south-eastern slope, and, as stated above, this patch is wholly surrounded by granite. On the bare upper part of the hill the relations between the two rocks are easily examined, and it is seen that no sharp divisional line can be drawn between them. The one appears to graduate into the other, often through a transitional zone of a rather coarse-looking or pegmatoid rock, a type common in other localities as an integral part of the banded gneissic complex. Thus, at the only place where the relations are clearly displayed, the gneiss is to all appearance inseparable from the granite. The locality and the situation of the patch of gneiss on the shoulder of the hill are consistent with the supposition that the original boundary of the large acid intrusion was not far above this place. The porphyritic quartz-felsite of the mountain-border belongs to a later phase of Tertiary igneous activity, and its posteriority to the gneiss is easily demonstrated. On the hill east of Loch Gainmhigh, a strip of gneiss nearly 100 yards long, with metamorphosed Torridon Sandstone adherent on one side, is enveloped in the felsite. The lower intrusion of felsite on Beinn nan Stac (fig. 4, p. 202) seems to be of dyke-like habit, forced in along the border of the lenticle of gneiss.

The relation of the gneiss to the ultrabasic and basic intrusions is yet to be considered. It is to this that we should look for a final test of the suggested Tertiary age of the gneissic rocks; for, on this hypothesis, the gneiss, or at least the acid rock which is its dominant element, should be newer than the massive intrusions. In the central part of Rum, near Loch Sgathaig and Priomh-loch, the gneiss is bounded in several places by peridotite and gabbro; and one patch, west of Priomh-loch Mòr, is entirely surrounded by those rocks. I have not, however, detected here any exposure of the actual junction, from which one might draw conclusions. The gneiss in this district has a high dip to the north, irrespective of the form of its boundary; but this does not imply that the gneissic

banding is truncated by later intrusions, for the same thing is seen in other places where the gneiss is in contact with sandstones or shales. Gneissic banding and foliation, though of the nature of fluxion-structures, are not necessarily parallel to the boundaries of the mass.

From the Dibidil district we obtain evidence of a more positive nature. Here the main body of gabbro has retired somewhat inland; but, as elsewhere, there are numerous small intrusions of that rock in the country fringing the mountains. These intrusions take the form of lenticles and dyke-like strips, some of which are closely associated with the gneiss, in several places forming an inconstant border to it. The strip of gneiss which occupies the lower part of the Dibidil River is partly bordered by gabbro on both sides, and again at its southerly termination. The relation suggested is that the gneiss has been intruded along the side of, and partly through, the gabbro, just as granites have been intruded beside and partly into gabbros at many other places in the Inner Hebrides. Where the junction is clearly exposed, direct proof of this sequence of intrusions is found. At a place on the left bank of the river, a little way below the ford, the gabbro is seen to be penetrated by tongues of gneiss running out from the main body, as well as by narrower reticulating veins consisting chiefly of the pegmatoid rock which here, as elsewhere, is a component element of the gneiss. At the same place, detached blocks of unmistakable gabbro are enveloped in the gneiss itself. This gneiss is quite typical, and the gabbro is indistinguishable from that of other intrusions in the district. Here, then, we seem to have ocular proof of the conclusion, already foreshadowed by other considerations, that the gneissic rocks of Rum belong to the great Tertiary suite of eruptions. The only alternative, with the evidence before us, is to assume the existence of an older group of gabbros identical in appearance with the Tertiary gabbro in the immediate vicinity—an artificial hypothesis not supported by any known facts.

Another enquiry, not yet touched, relates to the very significant distribution of the gneissic intrusions. The fact that all the occurrences noted are associated with the highly-disturbed belt of country suggests some connection between the gneissic structure and the crust-movements; of course, those of Tertiary date, which recurred, as has been noted, in places already affected by the much more intense Palæozoic disturbances. A like conclusion is enforced by an examination of the strike of the gneissic banding and foliation, which is not concordant with the boundaries of the several intrusive bodies, but seems to obey some larger law. The dips, almost always at high angles, are northerly in the central part of the island, inclining rather towards north-north-east on Beinn a' Bhàrr-shaibh. In the small intrusion of gneiss on the lower slope of Beinn nan Stac the dip is west-south-westerly. Rapid changes of strike and dip are found only in the Dibidil neighbourhood, where the older system of crust-movements had been especially vigorous,

and where, too, disturbance posterior to the intrusion of the gneiss was sufficiently intense to produce noteworthy brecciation in that rock. It may be plausibly conjectured that the movements of which this last effect is the witness were initiated somewhat earlier, and that the fluxion in the gneiss itself is related to it.

## V. THE COMPOSITION AND ORIGIN OF THE GNEISSES.

I have now to discuss the petrographical characters of the gneissic rocks of Rum. In doing so, I shall adopt the conclusion to which the field-evidence has led me, and treat the gneisses as a special facies of the Tertiary plutonic rocks of the region. It will be seen that this position is strengthened by many peculiarities of the gneissic rocks themselves, to be noticed below. One explanatory remark is called for at the outset. Considered simply as intrusions, the gneisses are to be correlated, as we have seen, with the granites, but, having regard to their actual materials, the granite-magma has supplied only one element, though the dominant one, of the gneissic complex. The basic and ultrabasic rocks have contributed in a minor degree, and so also to some extent have the Torridonian sediments. These various subsidiary components are for the most part much disguised, and have often quite lost their individuality in the resulting complex, for the acid magma by which they have been enveloped and impregnated has not only metamorphosed, but often partly or wholly digested them. In a word, much of the gneiss is a hybrid rock, and this composite origin frequently betrays itself in unusual mineral associations. Since the effect of my study of the rocks is to connect the gneisses, on petrographical as well as on geological grounds, with the Tertiary suite of intrusions, we will first glance at the occurrence of gneissic structures in rocks admittedly of Tertiary age in the same petrographical province.

Nine years ago, Sir Archibald Geikie & Mr. Teall<sup>1</sup> described the highly developed gneissic banding in the Tertiary gabbros of Druim an Eidhne, in Skye, and pointed out the instructive bearing of the phenomena described upon the origin of such gneisses as those of the Lewisian Series. The present writer has found that such banding affects in varying degree a considerable portion of the gabbros of both Skye and Rum, while it is much more prevalent, and attains a more striking development, in the more variable group of ultrabasic plutonic rocks in the same islands. The authors cited proved clearly that (at the locality described by them) the banding has resulted from the intrusion of a heterogeneous magma, which was drawn out into parallel streaks by flowing movement without any effective intermingling of the different portions. Such is undoubtedly the explanation of the

<sup>1</sup> Quart. Journ. Geol. Soc. vol. 1 (1894) pp. 645-59 & pls. xxvi-xxviii.

detailed structures in all these banded rocks, though the larger alternations seem rather to represent distinct and successive intrusions, with a stratiform disposition following the same direction. We may infer that the rarity of banding in the granites and granophyres of the same districts is connected with the greater homogeneity of the magmas from which these rocks have been formed, and a study of the several groups amply confirms this conclusion. Throughout the Inner Hebrides—not to go farther afield—the acid plutonic rocks are much more uniform, on a small as well as on a large scale, than the basic, just as these latter rarely approximate to the extreme variability of the ultrabasic.

At certain places in Skye, however, the acid intrusions assume locally a strongly gneissic structure, and the circumstances of these exceptional occurrences are very significant. They may be examined at more than one locality on Marsco, where considerable bodies of gabbro have been enveloped in, and attacked by, the granite-magma. The acid rock in these places is modified by the inclusion of a certain amount of gabbro-débris, which is found in various stages of digestion down to complete absorption, and the banded rocks form offshoots from the main body traversing the altered gabbro-mass. They compare closely with some of the more acid portions of the Rum gneisses, and are also, like these, intimately bound up with a purer pegmatoid rock, which suggests an effort of the acid magma to free itself from foreign contamination. These exceptional occurrences, in places where the relationships of the rocks are unequivocal, are especially instructive from the point of view to which we have been led. Primary gneissic banding in an igneous rock may be regarded as the result of flowing-movement in a heterogeneous magma. In these stratiform intrusions we may reasonably postulate a considerable degree of flow in acid and basic magmas alike, and the development of any pronounced banding will thus depend upon the greater or less heterogeneity of the magma. But heterogeneity may arise in two ways, illustrated on the one hand by the gabbros of Druim an Eighne and the peridotites of Allival, on the other by the veins on Marsco and the Rum gneisses. The requisite variability must be attributed in the former case to imperfect segregation of the differentiates from one parent magma, and in the latter case to imperfect commingling of distinct rocks (including rock-magmas), the presumable consanguinity of which is of a more remote degree. In a due recognition of this principle is contained the clue to the peculiarities presented by the gneissic rocks under discussion.

I proceed to consider, though without going deeply into petrographical details, the characters of the gneisses themselves. Most of them are, more or less markedly-acid rocks, of dominant quartzofelspathic composition: but of these prevalent acid rocks only a part are of a pure type, representing an unmixed granite-magma. This type is found, associated with other types, basic and hybrid, in all the localities mentioned, though it does not constitute the

principal portion of the exposures. Good examples may be examined in the neighbourhood of Priomh-loch Mòr and Loch Sgathaig, and by the roadside north of the latter. These rocks are in themselves devoid of any banded structure, although in their mode of association with other types in the complex they conform with the common parallel disposition. Apart from their mode of occurrence, there is nothing in their appearance to distinguish them from the ordinary granitic rocks of the island and of other islands in the Inner Hebrides. Their essential identity with these is borne out by a microscopic examination. There is a strong tendency to delicate micrographic intergrowths of felspar and quartz, imparting to the rocks the microstructure which is implied in the name 'granophyre,' as used by Rosenbusch. This is the most marked characteristic of the acid plutonic rocks of Tertiary age throughout the British area, the rocks of which I have spoken as granites, although I might with equal propriety follow Sir Archibald Geikie in applying to them as a group the name 'granophyre.' A rock of the type that we are considering has acid felspars and quartz as its chief minerals, and consists principally of micropegmatite. A certain portion of the felspar, and more rarely of the quartz, may form more or less distinct crystals, but the micropegmatite encroaches upon the borders, or even affects the interior, of the crystals. The felspars are orthoclase and oligoclase, of which the former builds the more regular and delicate intergrowths with quartz, while the latter more frequently builds distinct crystals. The ferromagnesian element is sometimes hornblende, sometimes biotite, while magnetite and apatite are found as minor accessory minerals. This description applies equally to the purely-acid portions of the gneissic complex, and to the prevalent type of the large granitic tract of Orval and the neighbouring hills. A medium texture prevails, but some of the rocks have rather a coarse-grained pegmatoid appearance in the field. These latter occur as strings or veins in the complex, and on Beinn a' Bhàrr-shaibh are interposed as a border between the gneissic and non-gneissic rocks.

The pure granophyric type graduates into another, which is still of thoroughly acid composition, but shows peculiarities which point to the intervention of some element of alien origin. Thus, from the little roadside-section near Loch Sgathaig comes a biotite-bearing granophyre [10492] answering to the above description, while close by, and inseparable from it, occurs a rock of precisely the same character, except that, in addition to the flakes of biotite, it contains very numerous little crystal-grains of hypersthene [10493]. The occurrence of a mineral so little expected in a granophyre is significant, and the explanation is not far to seek. It is found in the presence, in the immediate neighbourhood, of abundant inclusions or xenoliths of a dark close-grained rock, evidently of basic composition; and other specimens selected at this place demonstrate very clearly the origin of the pyroxene-grains by reaction between the basalt and the acid magma. These specimens have no marked gneissic banding, and they illustrate in a very instructive way

circumstances which in many other localities have been obscured by a more noteworthy amount of flowing-movement.

It may be remarked here, parenthetically, that the inclusion and partial or complete destruction of basic rock-débris by an acid magma, which will be seen to be so important a factor in the production of the gneisses of Rum, is entirely in accord with our reference of these rocks to the same great suite as the larger bodies which form the principal hills of the island. Nothing is more characteristic of the Tertiary intrusions of Britain as a whole than the frequent intimate association of widely diverse rock-types, often giving rise by admixture to rocks of very peculiar kinds. Sometimes angular fragments of a rock have become involved in a newer magma and entered into reactions with it; sometimes the earlier rock has been invaded before it was cooled, or even before it was completely solid, by the later and different magma; sometimes, again, the imperfect admixture has been effected in some intratelluric reservoir prior to intrusion. The intensity of the mutual reactions has been controlled by the temperature and other physical conditions implied in these different circumstances; but it has also depended upon the degree of difference between the two rocks involved, the maximum effects being found where a basic rock has been attacked by an acid magma. There has thus resulted, in different cases, a rock with evident xenoliths, more or less altered, a hybrid product with scattered xenocrysts, usually much disguised, or, in the extreme case, a rock which shows in a given specimen no direct indication of any foreign element. Even this last, however, will often betray its origin by something unusual in its mineralogical constitution.<sup>1</sup> Good examples of these various phenomena may be studied without going beyond the Isle of Rum. I need cite only one instance, that of the eastern border of the principal granite-tract, where it is conterminous with part of the large area of ultra-basic rocks. There is a zone of evident admixture, which in places attains a width of about 50 yards. Where this well-marked zone, with the appearance of a breccia, is wanting or much reduced, it is because mutual reactions of a more advanced kind have resulted in complete dissolution of the peridotite-xenoliths in the acid magma. The evidence of this is seen in little clots or patches rich in ferromagnesian silicates (often including hypersthene) scattered through the granite or granophyre to some distance from the line of contact. The final breaking-up of these has doubtless been facilitated by a certain amount of differential movement in the magma.

Effects of the same general kind as those just noticed, but with great variety in detail, have been studied by the present writer in many of the Tertiary intrusions of Skye; and a comparison of the phenomena with those of the Rum gneisses leaves no doubt that a

<sup>1</sup> On this point, see 'Igneous Rock-Series & Mixed Igneous Rocks' Journ. of Geol. [Chicago] vol. viii (1900) pp. 389-99. I have described numerous occurrences of xenolithic and hybrid rocks, with some discussion of the general questions involved, in a forthcoming memoir of the Geological Survey on 'The Tertiary Igneous Rocks of Skye.'

great part of the latter are susceptible of explanation on these lines. A minute description of the rocks would be merely an expansion of this general statement, and for our immediate purpose a few brief remarks will suffice.

Where recognizable xenoliths occur in rocks forming part of the gneissic complex, they are, if not in course of dissolution, at least highly metamorphosed, and their original nature is not always patent to observation. In some cases they are of a compact black rock, which looks like an indurated shale, and in thin slices shows a laminated structure marked by abundant brown mica and granular magnetite. There are, however, none of the special aluminous minerals, such as sillimanite, which usually characterize highly-metamorphosed argillaceous sediments, and the presence of porphyritic feldspars is proof of an igneous origin. The majority of the xenoliths clearly come from ultrabasic and basic igneous rocks, though often apparently of finer texture than the common peridotites and gabbros of the island. They usually illustrate an advanced stage of replacement, a term which I use to denote the transformations consequent upon interchange of substance with the enveloping acid medium. It is a common observation in other districts examined by me that such replacement may proceed almost without limit while the sharp boundary of the original enclosed fragment remains intact, and of this the Rum gneisses afford abundant illustration. The xenolith thus comes to be replaced by a cast or pseudomorph, preserving the former outline but consisting of a granular aggregate wholly of new formation, to which the acid magma has contributed. Granules of pyroxene are the principal elements of the replaced xenoliths. They are partly of augite, but more commonly of hypersthene, a mineral which might confidently be expected from the reaction of olivine with a magma rich in silica. The reciprocal modification of the acid matrix, essentially an enrichment in the dioxide-bases, shows itself in a somewhat diminished proportion of quartz and an increased prominence of the ferromagnesian silicates, lime-bearing feldspars, and magnetite. Pyroxene-granules are often abundant, but these are in great part mechanically detached from the borders of the transformed xenoliths. The micrographic structures, which rule in the purely-acid portion of the complex, are usually lost in these partly-basified products, a feature constantly observed in similar xenolithic and hybrid rocks in Skye.

Rocks of the general type described, sometimes graduating into pure granophyres, show little or no gneissic banding; and in the well-banded gneisses, which make up the principal part of the complex, xenoliths have usually been obliterated. This is easily understood. We have seen how the enclosed fragments are transformed to mere aggregates of granules, and it is evident that the preservation of their original outlines is contingent on a condition of tranquillity in the surrounding magma. Movement would quickly resolve the aggregates into detached granules, and indeed the thin slices enable us to verify this breaking-down process in various stages. Where strong fluxion has supervened, as is the case

in most parts of the complex, the process has, of course, gone much farther. Thus the flowing-movement, while bringing out more prominently the heterogenous composition of the rock-body, has effaced the evidence as to how the heterogeneity arose. The missing links are supplied by a comparative study of different localities. Given a granitic magma enclosing *débris* of more basic rocks, an irregular distribution of the *débris* such as is seen where the xenoliths are still traceable, reactions between the basic rocks and the acid magma of a kind familiar in many other districts, and that drawing-out of the whole by flowing-movement which is proved by the banded structure, we have a complete explanation of the principal part of the Rum gneisses.

There remain certain thoroughly-basic rocks which form bands in some parts of the complex, but make up only a small fraction of the whole. These illustrate another principle elsewhere abundantly exemplified in the British Tertiary suite, namely, the tendency of an acid intrusion to follow closely the line of an earlier basic intrusion, often accompanied by noteworthy reactions between the two rocks. I have not thus far expressed any explicit opinion as regards the source of the ultrabasic and basic xenoliths discussed above. It is possible that they were in part brought up by the acid intrusion, having been derived from underlying rock-masses; but of such concealed masses we have no other clear indication, the known intrusions of gabbro, peridotite, etc., being situated at higher horizons. We may perhaps suppose with more probability that the xenoliths are relics of ultrabasic and basic intrusions which occupied in part the present position of the gneiss, prior to the more voluminous intrusion of acid magma which destroyed them. This hypothesis has the advantage of accounting at the same time for the continuous or lenticular bands of basic rocks which are in places associated with the more acid and hybrid rocks as integral parts of the complex.

These basic rocks appear to have been of the nature of gabbros, now transformed by metamorphism, and in some measure by interchange of material with the acid magma. A dark hornblendic rock of this kind, with more or less evident banding and foliation, is a prominent part of the gneissic complex at a locality north-east of Priomh-loch Mòr. It has the general aspect of a medium-grained diorite [10733]. In a thin slice it is seen that the deep green hornblende, which makes up more than half of the rock, presents in places the crystal-outline proper to that mineral, proving that it is not merely pseudomorphic but has crystallized as such. The rest of the rock consists chiefly of a finely-striated plagioclase; but there is also some unstriated feldspar, which may be orthoclase, and a few little interstitial grains of quartz are seen. These last two minerals probably point to a certain impregnation of the recrystallized basic rock by the granitic magma.

For comparison I take another example from the small patch of gneiss enclosed in the porphyritic quartz-feldspar of the hill east of

Loch Gainmhich. The basic rock here forms a mere seam a few inches thick, and has presumably been more vulnerable to the invading acid magma. It is of rather coarse texture, and has a pronounced fissile structure, due to the parallel disposition of the crystals of hornblende, which is again the chief constituent [10495]. These crystals, ranging up to a quarter of an inch in length, are of ragged shape and of green colour. Orthoclase becomes here a more abundant element, while the accompanying striated felspar seems to be an oligoclase. Some quartz occurs, but only in the interior of the hornblende, where also strings of magnetite-granules and a little brown mica seem to have resulted from a certain corrosive action.

It is doubtful whether the sedimentary rocks have contributed in any sensible degree to the composition of the gneisses. At a junction of gneiss with pebbly grits to the east of Priomh-loch Mòr there is evidence of a certain amount of incorporation of the latter rock in the former, pebbles of quartz being recognizable in the gneiss for a short distance from the actual contact. The felspathic sandstone, which is the common type in the Torridonian, would probably be more easily attacked than a purely quartzose rock, and there is evidence at several localities in Rum that the sandstone has been partly fused in contact with an intrusion. Mr. Clough has noticed a like effect on the edge of peridotite-intrusions on the Isle of Soay, where a certain mingling of the fused sandstone with the ultrabasic magma can be verified. All my observations go to show, however, that any such action is of exceedingly limited extent. Again, at certain junctions of the gneisses with Torridonian shales it may be seen that the igneous magma has penetrated in thin leaves for a short distance along the laminae of the shale, the latter being highly metamorphosed. I have found nothing to suggest that these local effects have any significance in respect of the origin of the gneissic rocks. It is at least certain that merely metamorphosed sediments form no part of the complex, which consists wholly of rocks crystallized from igneous fusion.

## VI. SUMMARY OF CONCLUSIONS.

In conclusion I will indicate summarily the chief results to be deduced from the observations recorded above. It has been shown, firstly, that the highly-disturbed region of the North-Western Highlands, extending into the south-eastern part of Skye, is further prolonged into the Isle of Rum, where a belt of overthrust strata borders the principal high ground. It is perhaps not impossible that the main surface of movement here corresponds with the great 'Moine Thrust,' which Mr. Clough has traced through the Sleat district of Skye to within about 10 miles of our ground. It is, however, more probable that we have to do here with one of the less extensive displacements beneath, and in advance of, the great one. Its only effect, tectonically, in the mountain-border is to

cause lower parts of the Torridonian to rest on higher parts of the same series. On a smaller scale, too, the mechanical re-arrangement of the rock-masses affected is not of the most extreme type, being limited in general to contortion and brecciation. The mechanical conditions controlling these several processes form a subject of enquiry outside the scope of the present communication. I have, however, pointed out that the Torridonian strata forming the northern half of Rum, which I regard as, in a general sense, in their natural position, evince nevertheless abundant indications of disturbance on a small scale; and from this we may not improbably infer the existence of an important surface of displacement at no great distance above the present surface of the ground.

This inference is in some measure strengthened by the occurrence of an isolated patch of overthrust and highly disturbed rocks on Monadh Dubh, in the north-western part of the island. We cannot, however, assume that the surface of displacement in this place is identical with that of the mountain-border. Both the tectonic arrangement and the induced rock-structures seem to point to a higher order of disturbance; for the Cambrian limestones have here been involved with the Torridonian rocks, and, in addition to brecciation of a more advanced type than before, there has been a shearing of the sandstone to produce a schist or mylonite. The actual disposition of the rocks, as described above, has suggested that the overthrust seen on Monadh Dubh may be subordinate to one of more imposing magnitude at a somewhat higher horizon.

In Rum, as in Skye, the mapping proves that the 'thrust-planes' have in some places been bent into bold curves; and this folding is most probably referable, at least in great part, to a Tertiary epoch. It is certain that in both islands there was a belated and relatively feeble revival of crust-movements at a late date; and, though we cannot point to Tertiary overthrusts, we find locally evidence of considerable brecciation and comminution of rock-masses at a time posterior to the great plutonic intrusions. In this way must be explained the local brecciation of the gneiss near Dìbidil.

The second principal object of the present communication is to draw attention to a group of igneous gneisses in the central and south-eastern districts of Rum, to establish their Tertiary age, and to point out how the strong gneissic banding which they so frequently display has originated. As regards the question of age, we have seen that the rocks are intrusive in the disturbed Torridonian strata, that they are newer than the great system of crust-movements, and that they are found to send veins into the Tertiary gabbro. The evidence upon which this last statement rests has been observed only at a single locality, but it does not seem seriously open to question. There is further the consideration that where the gneiss is contiguous with the ordinary granite (or granophyre) of the western district, there appears to be a passage from the one rock into the other. Petrographically the purely-acid portion of the gneissic complex, which itself is not banded, is identical with the prevalent type of the admittedly-Tertiary acid intrusions; while

the other elements which enter into the complex may be interpreted as representing other known members of the Tertiary suite, disguised by the metamorphosing and corroding action of the acid magma, fused by it, and forming with it various xenolithic and hybrid rocks.

In their paper on the banded gabbros of Skye, Sir Archibald Geikie & Mr. Teall, after demonstrating the origin of the gneissic structure there by fluxion in a heterogeneous rock-magma, urged the application of the same principle to some gneissic rocks of much greater antiquity. The facts now recorded suggest a certain extension of the idea there thrown out. It appears that the requisite heterogeneity, which in some cases arises from imperfect differentiation, may in other cases be brought about by admixture; and that there may be produced in this way banded rocks which, although of purely igneous origin, present unusual mineralogical associations, and do not readily find a place in any systematic scheme of normal igneous rocks. Whether this principle also may have an application beyond the particular case described above is a question which I shall not presume to decide.

#### EXPLANATION OF PLATE XIV.

Geological sketch-map of the Isle of Rum, reduced from the field-maps to a scale of 1 inch to the mile. In order to avoid needless complication the inland lochs and streams are omitted, as well as the less important hills; also all geological details not relevant to the subject of the paper; in particular, the very numerous small plutonic intrusions, dykes, and sheets of Tertiary age.

The area not yet surveyed, in the south and south-west of the island, is occupied wholly by Tertiary igneous rocks, excepting only the southern termination of the disturbed Torridonian belt.

#### DISCUSSION.

Prof. JUDD congratulated the Author on the splendid work which he had been doing in the Inner Hebrides, and especially in the little-known island of Rum. He had himself confined his necessarily rapid traverse of that island (nearly thirty years ago) to the great igneous masses, and had paid little attention to the Torridonian rocks, but the account given by the Author of the disturbances undergone by these ancient rocks, as well as of gneissic structures formed in igneous masses near their planes of junction, was of a most interesting and suggestive character.

Prof. BONNER said that he was not likely to differ from the Author's interpretation of the gneisses, because he had already, on more than one occasion, called attention to the formation of banded gneisses and hornblende-schists by the intrusion of an acid into basic rocks, as in Cornwall and Sark. He thought that sometimes there was, though not very commonly, local melting of a more basic and solid by a more acid and liquid material, and sometimes a large mass at a very high temperature broke into and mixed with other large masses, which also were extremely hot and perhaps not

completely solidified; so the two were drawn out together, as in the common experiment of making a colour-banded glass.

The PRESIDENT, after referring to the great theoretical interest of the paper and to its richness in detailed observations, enquired whether the direction of overthrusting in Rum (which, to judge from the sections, appeared to have been towards the south-east, and consequently different from that in the North-Western Highlands generally) was a local phenomenon only, or was more or less regional. He gathered that the Author practically accepted the view that the origin of the gneissose banding, and its attendant phenomena, was due to the injection and consolidation of a heterogeneous magma during crust-movement. Referring to some observations of his own, made during a visit to Norway in 1890, he had himself been led to the opinion that, in some instances at least, the phenomena might be owing to the differentiation of a single original magma cooling in more or less laccolitic conditions under a creeping but irregularly-moving rock-cover. The parts of the collective mass might present all varieties of structure, differentiation, and injection—from those in which the material remained practically homogeneous, through stratiform stages and areas of more or less differentiated material where affected most by the crust-movements, to the final stages where the whole, practically cooled, mass became fissured and injected by material, in part segregated, and in part derived from greater and still unconsolidated depths below. A fine example is cut through in the roadside cliffs at Vik, at the head of the Hardanger Fiord, which would well repay a detailed study.

The AUTHOR thanked the speakers for their remarks. With reference to Prof. Bonney's observations, more especially concerning the banded rocks of the Cornish coast, he (the speaker) had understood that the structures there were attributed in the main to the deformation of solid rock-masses. He fully agreed with Prof. Bonney in holding that the dissolution and absorption of an earlier igneous rock by a later igneous magma had often been facilitated by the circumstance that the former was still hot, or even not wholly consolidated, when invaded by the latter.

In reply to the President, he said that, in Rum as in Sutherland, the direction of the Mid-Palæozoic crust-movements was from south-east to north-west. The much feeblar Tertiary disturbances were indicated by brecciation, and probably by folding, but he was not able to decide from which quarter the thrust at that epoch was directed.

